

# GEST

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**Abstract.** Galactic Exoplanet Survey Telescope (GEST) was proposed for a discovery mission to search for microlensing terrestrial planets toward the Galactic bulge and also Kuiper Belt Objects (KBOs) that are believed to hold vital information of the early history of the solar system. Microlensing planet search method is hinged on photometric singular behavior of lensing (refraction) that is due to discontinuities in the distribution of photon paths whose phenomenon is better known in total reflection. The singularities (caustics) directly translate into potentially large planetary signals but the small size of the caustics imposes four essential requirements for earth mass planet searches: massive survey, angular resolution, temporal resolution, and continuous monitoring capability in a statistically stable observing condition. A 2m scale wide FOV space telescope with a large focal plane such as the GEST meets the needs.

Habitability of earth mass planets in the habitable (liquid water) zone is suspected to depend crucially on a giant planet near the snowline. The large mass of the giant planets makes the planetary caustics larger and easier to detect them in abundance. In microlensing, one needs not wait 12 years to detect a jupiter at the Jupiter orbit (5 AU) unlike in other planet search methods (doppler, astrometry, transit) because the planetary microlensing events will complete their courses within 50 days or so – 70 times shorter!

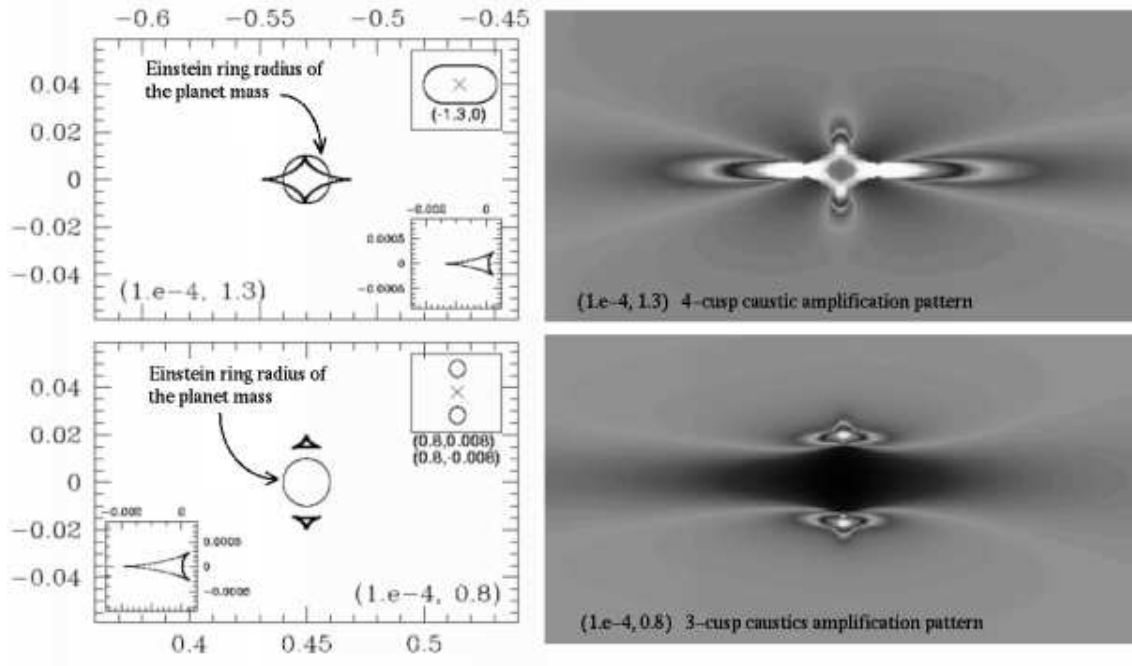
Close-in giant planets of the bulge stars will be registered as transits in the microlensing data base and will form a valuable platform for comparison studies of the planets from different detection methods and different environments.

When the Galactic bulge is behind the sun, the GEST will be ideal for high resolution mapping of the large scale structures which will include weak lensing by dark matter, quasar lensing and host galaxies, strong lensing by clusters, and a large volume of galaxies, which with selective follow-up measurements of whose redshifts and IR images will shed light on the dark stuff (matter, energy, essence, extra dimensions, topological defects, ... ).

**Gravitation, Relativities, Microlensing and Planets** Microlensing involves both special and general relativities in a most trivial way: the spacial warp due to lensing masses is scanned in time by special relativistic particles (photons) emitted from the lensed source and the general relativistic effect is contained in a factor 2. In microlensing, none of the 3 D's of lensing – delay, deflection, and distortion – are measured unlike in cosmological lensing because the time of flight differences and the image sizes and separations are too small. What is measured

is the total magnification of the images that varies in time because of the relative motion of the lens and the lensed as seen from the observer. Microlensing light curves are essentially smooth – characteristically smooth – except at caustic crossing discontinuities. Even the discontinuities are characteristically orderly and smoothed over the size of the source (lensed) star. So, given sufficient quality of data, microlensing light curves are easily distinguished and identified against the background of variable stars and flare stars.

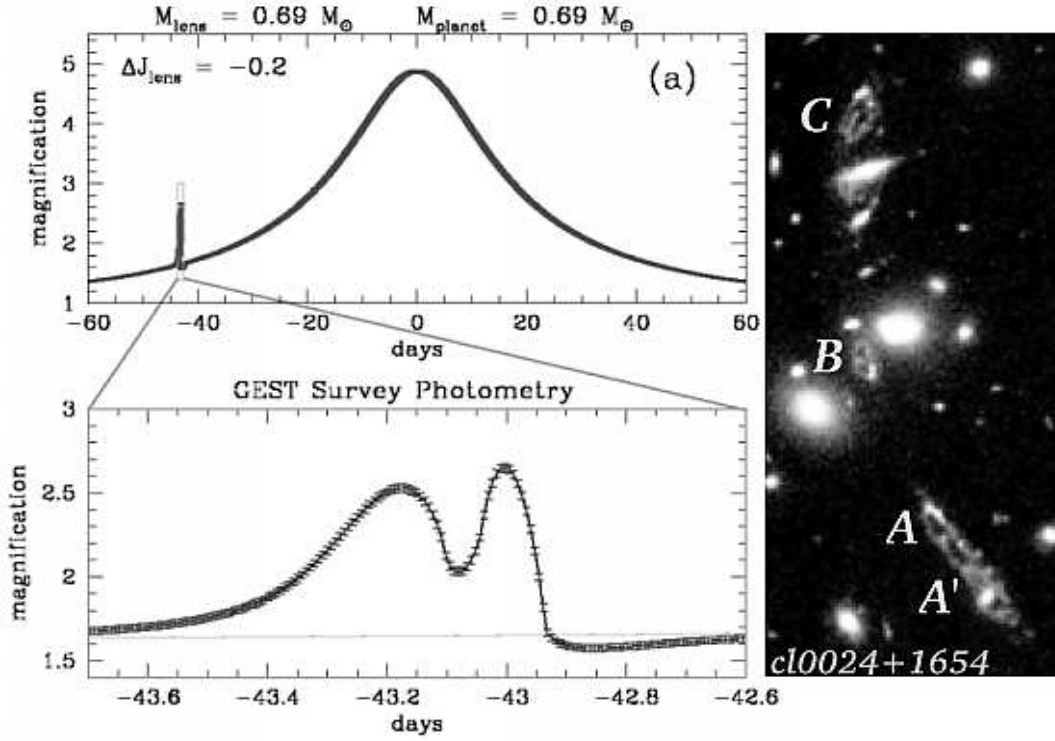
A microlensing planetary system will be discovered as a low multiplicity  $n$ -point lens. The interference pattern of the Newtonian potentials of the masses of the host star(s) and planets determines the angular positions, sizes, and strengths of



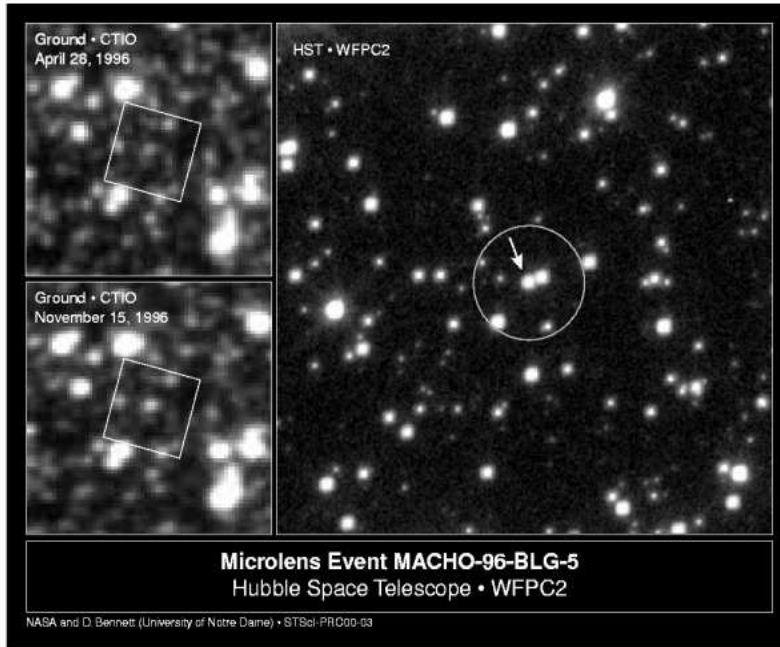
**FIGURE 1.** A planetary binary lens of a given mass fraction (here  $10^{-4}$ ) has two types of caustics that contribute to planet detections. When the separation ( $\ell$ ) between the star and the planet is larger than Einstein ring radius ( $= 1$ ), the planetary caustic has 4 cusps and is located between the star and the planet. When  $\ell < 1$ , two 3-cusped caustics jointly define the planetary caustic region. Shown are the cases of  $\ell = 1.3$  and  $\ell = 0.8$ . A cusp can be considered a point caustic with directionality, and the right panel exhibits varying magnification power of the cusps. Compare the sizes of the caustics and caustic regions. The Einstein ring of the planet as a single lens is commonly used as a rough estimator of the planetary caustics and is shown at the centers of the caustic planes. As a source star traverses the terrain of a planetary caustic, the light curve develops telltale “wavelets”. The star is at the coordinate origin and the 4-cusped stellar caustics (resembling arrowheads) are shown in the insets. The planet positions are shown (marked by  $\times$ ) in relation to the planetary critical curves which are centered around  $(-1.3, 0)$  and  $(0.8, \pm 0.008)$ . See Bennett and Rhie (1996) for more details of the caustic regions and lensing zones.

the caustics – the planetary signal generators. The caustic curve of a planetary system lens consists of a stellar caustic and planetary caustics. See figure 1 for the case of planetary binary lenses. The stellar caustic dominates the behavior of the planetary system as a gravitational lens except in the planetary caustic regions. The planetary caustics behave like small magnifying glasses that modify the would-be single lens light curve by the host star. The “size of the planetary caustic” (circles in figure 1) of an earth mass planet with mass fraction  $\epsilon = 3 \times 10^{-6}$  is  $\approx$  a few  $\mu$ as.

**Ground-based Searches for Earth Mass Planets?** The previous estimations of the feasibility of finding earth mass planets from the ground were based on the idea that turn-off stars (brighter than main sequence stars and smaller than gi-



**FIGURE 2.** The photometrically singular nature of the caustics allows detection of earth mass planets ( $\epsilon = 3 \times 10^{-6}$ ) with large S/N via microlensing. It is essential that the backlighting beam size (size of the source star) is sufficiently smaller than the size of the caustics in order to be able to reconstruct the magnification pattern and so the lens parameters from light curves. Here the lensed star is a main sequence star and the light curve has been sampled every 10 minutes (Bennett and Rhie 2000). The caustic singularity is associated with creation of two highly magnified images. The blue galaxy images A and A' lensed by cl0024+1654 seem to be one such pair conjoined at the critical curve which we believe is due to local mass concentrations. The image A' was reconstructed in the fit by Tyson et al. (1998) but has so far been ignored by other authors.



**FIGURE 3.** A typical Galactic bulge field is seen from the ground and space. The HST frame on the right is the image of the area inside the square boxes on the ground based images (from CTIO) on the left. The circle in the HST image indicates the seeing disk of the CTIO observation shown in the left bottom panel. In the color magnitude diagram of ground based observations, the main sequence (MS) stars inside the circle in the HST frame will show up as a “turn-off” star that is a few times brighter than a main sequence star. Since the microlensing beam - size of the Einstein ring radius - is small  $\approx 1\text{mas}$ , only one of the MS stars is lensed (here arrowed) and the blended light from the unlensed MS stars adds photon noise and diminishes the effective amplification of the observed light curve. For example, a 10% signal will drop to 3.5% with 1.73 times larger error bars.

ant stars) can be surveyed as source stars [10,1,4,7]. The caustic regions in figure 1 were calculated with the size of a turn-off star ( $3R_{\odot}$ ). However, it is a false assumption that was derived from a color magnitude diagram of ground-based observations of the crowded Galactic bulge fields. The alleged turn-off stars are mostly blended main sequence stars (see figure 3). More recent HST data show that turn-off stars are indeed rare [6] as one would expect from stellar evolutions. This is detrimental to ground-based searches for earth mass planets because of the large seeing disks. It is also the case that the moon closely accompanies the bulge during the high bulge season. With a 4m scale dedicated telescope at the best site (such as dedicated VISTA in Paranal), one can detect earth mass planets, but it takes a very long time to acquire sufficient statistics. The details are being calculated and will be reported in the revised version of [2].

**GEST, Planets, KBOs, and Large Scale Structures:** GEST is an ongo-

ing effort to search from space for microlensing planets in the Galactic bulge and the disk. The lack of close-in giants in the globular cluster 47 Tucanae indicates the possibility of metallicity constraints on the formation of planets or density constraints on the survival of the planets [3]. Galactic bulge is relatively metal rich ( $\approx$  solar metallicity in average) and is expected to be rich with terrestrial planets which may have been habitable when the Galaxy was younger. Gonzalez et al. [5] predicts massive terrestrial planets in the bulge, and GEST can explore the metallicity effect on the terrestrial planet mass limit. Ejection of planets is a commonality according to numerical studies, and GEST can detect the free-floating planets further constraining the planet formation and evolution scenarios. Microlensing is the only means to find mature free-floating planets.

Recent studies of habitability of planetary systems find a strong correlation between habitable terrestrial planets and jovian planets [8], and this throws a double jeopardy for most of the planet search efforts: small mass of terrestrial planets and long orbital period of jovian planets. Microlensing is a peculiar method that can handle the both challenges with ease.

In cosmological lensing, information is extracted from the spatial intensity distribution of the photons in the images. In order to reconstruct the mass distributions and extract the cosmological parameters accurately, it is crucial to find systems that offer sufficient number of constraints which in turn requires wide and deep imaging with an angular resolution of a small fraction of an arcsecond. Excellent systems can be followed up by the NGST or ground-based adaptive instruments for further information.

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